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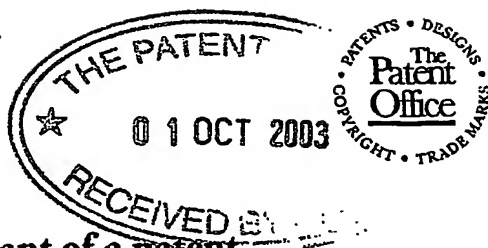
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1/77  
02OCT03 EB41466-2 002890  
P01/7700 0.00-0323001.8

# Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

1 OCT 2003

The Patent Office

Cardiff Road  
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1. Your reference

RSJ07917GB

2. Patent application number

(The Patent Office will fill this part in)

0323001.8

3. Full name, address and postcode of the or of each applicant (underline all surnames)

Oxford Instruments Plasma Technology Limited  
Old Station Way  
Eynsham  
Witney  
Oxon  
OX8 1TL

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

813 4272001

4. Title of the invention

APPARATUS AND METHOD FOR PLASMA TREATING  
A SUBSTRATE

5. Name of your agent (if you have one)

Gill Jennings & Every

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

Broadgate House  
7 Eldon Street  
London  
EC2M 7LH

Patents ADP number (if you know it)

745002

6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.

Country

Priority application number  
(if you know it)

Date of filing  
(day / month / year)

7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute (see note f)

Number of earlier UK application

Date of filing  
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8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request?

YES

Answer YES if:

- a) any applicant named in part 3 is not an inventor, or
- b) there is an inventor who is not named as an applicant, or
- c) any named applicant is a corporate body.

Otherwise answer NO (See note d)

## Patents Form 1/77

9. Accompanying documents: A patent application must include a description of the invention. Not counting duplicates, please enter the number of pages of each item accompanying this form:

Continuation sheets of this form

Description	12
Claim(s)	4
Abstract	
Drawing(s)	3

10. If you are also filing any of the following, state how many against each item.

### Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for a preliminary examination and search (Patents Form 9/77)

Request for a substantive examination (Patents Form 10/77)

NO

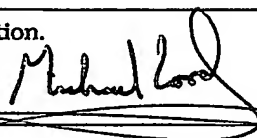
Any other documents (please specify)

11. I/We request the grant of a patent on the basis of this application.

For the applicant

Gill Jennings & Every

Signature



Date 01/10/03

12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom

LORD, Michael

020 7377 1377

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APPARATUS AND METHOD FOR PLASMA TREATING A SUBSTRATE

The present invention relates to an apparatus and method for plasma treating a substrate.

5 Plasma treatment systems of various designs are known for performing treatments such as the etching of substrates or the deposition of thin layers upon substrates. This is achieved by the formation of plasmas within low pressure gases.

10 The maximum etch/deposition rates achievable are of particular practical importance and various apparatus and process parameters are modified to control these rates. Such parameters include the size of the reaction chamber, the choice of precursor gases, the plasma power, the gas  
15 flow rate, the gas pressure and the electrical potential bias applied to the substrate.

One such prior art system is disclosed in WO02/056333 in which a plasma is generated within a relatively narrow upper sub-chamber using RF coils. The active species  
20 produced then migrate into a larger lower chamber beneath within which a target substrate is positioned.

Remote or downstream plasma sources are also known in which gaseous species are ionised and excited at a location which is distant from the workpiece. Typically the  
25 excitation occurs within a pipe or duct and the active species flow along the pipe to then interact with the workpiece. In order to treat a large workpiece such a pipe is arranged to open into a larger chamber accommodating the workpiece.

30 In some prior art systems (such as that disclosed in WO02/056333), an expansion region is provided by the provision of a large chamber adjacent the plasma generation region. Such an expansion chamber provides for the homogenisation of the species generated within the plasma.  
35 Whilst this has some positive effects with regard to the uniformity of the treatment upon the substrate surface, it is often detrimental to the treatment rate, adds to the

cost of the equipment and complicates the set-up procedure associated with the apparatus.

There is therefore an ongoing desire within the industry to provide improved apparatus with higher process rates whilst maintaining the uniformity of the treatment effect upon the substrate.

In accordance with the first aspect of the present invention we provide an apparatus for plasma treating a substrate comprising:-

10 a chamber within which one or more gases are caused to flow;

a plasma generator for causing the gas(es) within the chamber to form a plasma, thereby generating at least one species; and

15 a guide for directing the gas flow containing the species towards the substrate;

wherein the apparatus is arranged such that the width of the plasma in use is greater than that of the substrate, the difference between the widths defining an outer region of plasma, and wherein the guide is adapted to direct species from at least the outer region, towards the substrate.

In addition, in accordance with a second aspect of the present invention we also provide a method for plasma treating a substrate comprising:-

causing one or more gases to flow within a chamber; forming a plasma from the gas(es) within the chamber using a plasma generator, thereby generating at least one species; and

30 directing the gas flow containing the species towards the substrate;

wherein the width of the plasma in use is greater than that of the substrate, the difference between the widths defining an outer region of plasma, and wherein the species are directed from at least the outer region, towards the substrate.

We have realised that, in contrast to prior art systems, improved process rates can be achieved by the use of a guide for directing the gas flow within the apparatus onto the substrate and thereby directing the species  
5 produced within the plasma onto the substrate. Whilst in the past plasma treatment rates have relied upon diffusion and low velocity mass transport effects, the present invention recognises that, a directed flow of species onto the substrate can produce much higher etch rates but  
10 without a corresponding detrimental effect upon the uniformity of the resulting substrate treatment.

The present invention differs from known systems in that such systems involve an expansion of the cross sectional area of the flowing gas to treat larger  
15 substrates. With the invention, the reverse is true. Indeed the increase in processing rate obtained with the invention is due to a concentration of species from a larger diameter into a smaller diameter. A further distinction can also be made in that preferably the plasma  
20 source of the invention is arranged in close proximity with the workpiece. It is required to be no more remotely positioned than the physical separation caused by the existence of the guide.

The guide allows the width of the plasma (that is, its  
25 lateral dimension) to be greater than that of the substrate. The difference between the width of the plasma and the substrate defines an "outer region" of the plasma. The guide directs the species from at least this outer region onto the substrate. The advantage of this is that,  
30 because of the skin effect (in the case of electromagnetic generation) or plasma sheath effects (in the case of powered electrodes), the majority of the energy from the plasma generator couples to the plasma in a peripheral "active" region. In practice this region ordinarily  
35 extends inwards from the periphery of the plasma by a few centimetres. It is therefore desirable to direct the species from the most active region (where their

concentration is highest), directly onto the substrate by the use of the guide. The nature of the active species may change in transit from the active region to the substrate: either original or derived species may have useful effects on the substrate. The term "species" herein is intended to comprise the original and/or the derived species.

The width of the plasma is defined by the form of the plasma generation device and the volume within which the corresponding precursor gas(es) is contained. Depending upon the relative width of this region with respect to the substrate, the active region can be either fully or partially contained within the outer region mentioned above. With a cylindrical chamber, and a circular substrate surface, typically the active region is approximately toroidal.

The guide is therefore preferably adapted to direct towards (onto) the substrate at least the species generated substantially at or adjacent the periphery of the plasma, that is, at least in the active region mentioned above.

The substrate is typically spaced apart from the active region of the plasma and may be positioned within the upper part of the chamber, close to the active plasma, or further away in the lower part of the chamber. For example it may be positioned within a sub-chamber or within a dedicated chamber. In either case, the part of the chamber separating the substrate from the plasma generating region may be narrower in width than the region within which the plasma is generated. In this case, the chamber walls themselves may comprise the guide. This is quite different to many prior art systems in which the plasma generation region of the chamber is substantially narrower in width with respect to other parts of the chamber.

The guide may take a number of other forms, for example as a funnel. Preferably the guide is substantially a hollow conical frustum in shape. In such a case it typically has a linear cross-section upon either side of its central axis. In alternative forms, a curved section

may be provided. Furthermore, the guide may be part linear and part curved in section.

Typically the guide is arranged with respect to the substrate such that the gas flow adopts a symmetrical flow over the substrate surface. However, the guide may be adapted to cause a nett flow of the species across the substrate by either providing asymmetry within the guide itself or by positioning the guide asymmetrically with respect to the substrate. This avoids the possibility of producing a "Stagnation point" of low reactivity at the centre of the substrate.

The guide is typically positioned directly between the region in which the plasma is generated and the substrate. This provides an additional advantage in that the guide may be adapted to shield the substrate from electro-magnetic radiation originating from the plasma. This shielding preferably includes reducing the amount of substrate having a direct line of sight with the active regions of the plasma, and also in preventing radiant heat impinging upon the substrate from the hottest parts of the chamber.

As is known, plasmas may comprise various kinds of active species, including ions, electrons and reactive neutral entities. In some cases it is desirable to prevent charged species from reaching the substrate surface and in such situations, preferably the guide further comprises a plasma termination device, which is operative to attenuate the supply of electrically charged species to the substrate. This may be achieved by the use of a conducting mesh as part of the guide device through which the gas flow passes. Alternatively or additionally, a magnet system may be used so as to divert the flow of electrically charged species.

Conveniently, the guide may also be provided in a form such that it is releasably coupled to the apparatus so as to allow the use of different guides for different specific processes.



Contact of reactive species with various surfaces, such as those of the guide, may cause detrimental reaction with the surface in question and a reduction in the active species concentration. Therefore preferably the material(s) chosen for at least the surfaces of the guide which contact the gas flow, is arranged so as to reduce any quenching effect of the active species. Typical examples of such materials include Alumina or Nickel.

The detrimental effect of contact between the species and the guide can also be mitigated by the heating of the guide to a predetermined temperature and preferably the apparatus further comprises a suitable heating system to effect this.

The gas flow is established and controlled by a gas flow system which is adapted to supply the one or more gases to the chamber and to remove the gases and species from the chamber. Such a system may typically comprise one or more vacuum pumps, gas bottles, regulators and conduits. Typically the gas(es) are supplied to the chamber in the region at or adjacent that in which the plasma is generated and vented from the system on the opposite side of the substrate to this region.

In order to maximise the efficient use of the active region of the plasma, preferably the apparatus further comprises a deflector device within the chamber for directing the gas(es) introduced into the chamber towards the most active region(s) of the plasma. This ensures the supply of the fresh gas to the regions, maximises the system efficiency and also maximises the concentration of the species generated.

The invention is not limited to any particular form of plasma generator and suitable examples of such generators include an induction coupled plasma generator, a microwave plasma generator or electrode-based (capacitive) plasma generator.

The substrate is supported within the gas flow using suitable support means. Examples of such means include a

table or platten upon which the substrate is positioned or a device to which the substrate is mounted and held in position. Preferably the support means (and therefore the substrate) is positioned within the chamber.

5       Alternatively, the substrate may be positioned in a separate chamber with the guide being positioned between the chamber in which the plasma is generated and the chamber in which the substrate is supported.

10       In order to provide further adaptability, the support means is preferably moveable with respect to the plasma generation region so as to provide the user with the facility of a controllable distance between the plasma and the substrate. The moveable nature of the support provides for the use of different plasma treatments. The guide may  
15       also be mounted to the support means when in either the static or moveable form. This is particularly advantageous when used with a moveable support since this allows advantage to be taken of the increased species flux provided by a closer proximity to the active plasma region.

20       In order to further control the reaction of the species with the substrate, the apparatus preferably further comprises an electrical supply system which is adapted to supply an electrical potential difference to the support. Such a potential may be a DC signal but more  
25       preferably, it is an RF signal.

30       Preferably during the performance of the method in accordance with the second aspect of the invention, this electrical potential is provided to the substrate via the support means so as to control the interaction of the species with the substrate.

35       In one example an induction coupled plasma is used in association with a low pressure process, where the pressure of the gas(es) within the chamber is between about 1 and 15 Pascals. A number of different types of precursor plasma gases may be used (including mixtures thereof) examples including SF<sub>6</sub>, Chlorine, Fluouro-carbon compounds (e.g. CF<sub>4</sub>, C<sub>4</sub>F<sub>8</sub> etc) nitrogen, oxygen and Silane.

The method may therefore be used in any suitable plasma treatment, such treatments typically including etching treatments and deposition treatments.

5 An example plasma treatment apparatus and method according to the present invention will now be described with reference to the accompanying drawings, in which:-

Figure 1 shows a side view, partly in section, of apparatus according to the example;

Figure 2 is a flow diagram of the method; and

10 Figure 3 shows the gas flow within the apparatus.

Plasma treatment apparatus according to the example of the invention is shown in Figure 1. The apparatus comprises a chamber 2 in the form of a cylinder, the cylinder in this case being vertically oriented along its axis and with the diameter of the chamber being about 380 millimetres. A series of induction coils 3 are provided surrounding the upper part of the chamber, the coils forming part of an induction coupled plasma generator 4. The position of the plasma generator 4 around the upper part of the chamber defines a plasma generation region 5. A substrate support 6 is provided in a lower part of the chamber, this taking the form of a circular table arranged symmetrically about the cylinder axis and having an upper surface 7 upon which a substrate 8 is placed when in use.

25 The substrate holder 6 is arranged to be moveable axially as indicated at 9 by the provision of a screw thread.

The substrate support 6 is provided in the lower region of the chamber defining a substrate region generally indicated at 10.

30 An intermediate region 11 separates the upper plasma generation region 5 and the lower substrate region 10. A frusto-conical guide 12 is positioned within this intermediate region 11. This is arranged effectively as a funnel with the broader funnel "mouth" being provided at the top, adjacent the plasma generation region 5, and facing towards it. As can be seen in Figure 1, the guide

12 is arranged such that an aperture 13 is provided in the lower part of the guide. This aperture is approximately the same diameter as that of the substrate 8 (which in this case is a circular substrate).

5       The upper mouth of the frusto-conical guide in turn has a diameter approximately equal to that of the chamber in the plasma generation region 5.

10       A gas inlet 14 is provided in the centre at the top of the chamber 2. One of more precursor gases (from which the plasma is generated) are supplied along a conduit 15 from a gas supply 16, the conduit and gas supply forming part of a gas flow system for the apparatus.

15       Beneath the inlet 14 within the chamber, a deflector 17 is positioned centrally so as to deflect the gas(es) entering the chamber towards the chamber periphery.

20       The chamber is exhausted through an outlet 18 positioned at one side of the chamber base. An exhaust conduit 19 and corresponding vacuum pumps (turbo-molecular and rotary pumps) 20 are provided to achieve this, these components also forming part of the gas flow system for the apparatus.

25       Optionally, a conductive mesh or magnet system may be provided as part of or adjacent to the guide 12, these being indicated schematically at 25. Such devices may be used where it is desirable to terminate the plasma at the edge of the plasma generation region 5, these devices therefore acting as a plasma terminating device. An electrical supply 31 is also provided so as to power such a device where necessary. An additional electrical supply 30 is connected to the substrate support 6 so as to provide an RF bias to the substrate 8. This allows further control of the interaction of the species with the substrate as mentioned earlier. As indicated in Figure 1, a further electrical supply 32 may also be connected to the guide 12 when the guide also comprises a heating device, so as to heat the guide during use to a temperature of between about 35   100 and 200°C.

The operation of the apparatus is now described with reference to Figures 2 and 3 from the point of view of an amount of gas flowing through the apparatus during use. It will be appreciated, that despite the steps described below, the method is effectively steady state during operation. Prior to these steps, the substrate is loaded into the chamber, the chamber is evacuated and the gas flow at the predetermined pressure is established.

Referring to Figure 2, the gas in question firstly leaves the gas supply 16 and passes down the conduit 15 before entering the chamber via the inlet 14 at step 100. The gas flow is indicated schematically by the arrows 60 in Figure 3. In the present example the gas is sulphur hexafluoride ( $\text{SF}_6$ ).

At step 101 the gas entering the chamber is deflected outwards towards the side walls of the chamber by the deflector 17. A plasma is present within the chamber due to the stimulation of the gas within the region 5 by the plasma generator 4. In the system illustrated in Figure 1, the maximum energy is imparted within a roughly toroidal region indicated at 35. It will be noted that the gas is deflected into this region by the deflector 17.

At step 102, the gas approaches and enters the toroidal region 35. Here the energy provided by the plasma generator 4 is at a maximum and this readily causes the newly arrived gas to dissociate into plasma species. Various highly reactive species are formed as a result within the gaseous phase and subsequently, these species are carried downwards by the gas flow until they are redirected by the guide 12 at step 103.

At this stage, if a plasma termination device 25 is present, any charged species are either deflected or neutralised at the plasma termination device 25, incorporated into the guide 12.

At step 104, the gas exits the aperture 13 and impinges upon the upper surface of the substrate 8. Interaction of the substrate surface with the species

contained within the gas then occurs at this stage (step 105), so as to produce etching, deposition or modification, depending upon the parameters and gases used.

5 If an electrical bias is applied to the surface of the substrate during this process then this bias has a short-range effect and modifies the energy of the charged species striking the surface. The deposition or etching effect is therefore influenced accordingly.

10 At step 106 the gas then flows over the outer edge of the substrate and downwards to be exhausted from the chamber via the outlet 18, exhaust conduit 19 and vacuum pumps 20.

15 In order to test the efficacy of the apparatus and method described above, experiments were performed with a pure  $\text{SF}_6$ , silicon etching process on blank 100 millimetre diameter silicon wafers, these each acting as the substrate 8. A plasma source with a diameter of 380 millimetres was used (this being the diameter of the chamber 2). A 100 millimetre electrostatic wafer holder was used as a  
20 substrate support 6. An induction coupled plasma generator was used with a power of 5 kW operating at 2 MHz. In addition, an RF potential was applied to the substrate via the substrate support, this having a power of 25 Watts and operating at 13.56 MHz. The  $\text{SF}_6$  pressure in the chamber  
25 was 35 millitorr (4.66 Pascals) with a flow rate of 500 sccm (standard cubic centimetres per minute, as is well known within the art).

Experiments were performed in identical apparatus with and without the use of the frusto-conical guide 12. In the  
30 apparatus without the guide, the gas flow was not re-directed onto the substrate surface, and a significant proportion of the species generated in the plasma generating region would pass by the substrate holder and not interact with the substrate. In the apparatus fitted  
35 with the guide, all of the species generated in the plasma generation region and contained within the gas flow would be re-directed onto the substrate surface.

The measured etch rates were found to be as follows:-

Standard ICP380("Control"): 6.73 $\mu$ m/min  
With the guide in place: 13.52 $\mu$ m/min

5

The use of the guide 12 doubled the observed etch rate in these experiments. The etch uniformity was also investigated in the apparatus with the guide and found to be  $\pm 2.3\%$ . and well within the requirements of industrial practice.

10

These experiments therefore indicate that the apparatus and method according to the present invention provides a significant improvement in the plasma treatment of substrates.

15

CLAIMS

1. Apparatus for plasma treating a substrate comprising:-  
a chamber within which one or more gases are caused to  
5 flow;  
a plasma generator for causing the gas(es) within the  
chamber to form a plasma, thereby generating at least one  
species; and  
a guide for directing the gas flow containing the  
10 species towards the substrate;  
wherein the apparatus is arranged such that the width  
of the plasma in use is greater than that of the substrate,  
the difference between the widths defining an outer region  
of plasma, and wherein the guide is adapted to direct  
15 species from at least the outer region, towards the  
substrate.
2. Apparatus according to claim 1, wherein the guide is  
adapted to direct towards the substrate at least the  
species generated substantially at or adjacent the  
20 periphery of the plasma.
3. Apparatus according claim 1 or claim 2, further  
comprising a deflector device within the chamber for  
directing the gas(es) introduced into the chamber towards  
the most active region(s) of the plasma.
- 25 4. Apparatus according to any of the preceding claims,  
wherein at least part of the guide is substantially curved  
in section.
5. Apparatus according to any of claims 1 to 3, wherein  
the guide is substantially linear in section.
- 30 6. Apparatus according to claim 5, wherein the guide is  
substantially a hollow conical frustum.
7. Apparatus according to any of the preceding claims,  
wherein the guide is adapted to cause a nett flow of  
species across the substrate.
- 35 8. Apparatus according to any of the preceding claims,  
wherein the guide is adapted to shield the substrate from  
electromagnetic radiation originating from the plasma.



9. Apparatus according to any of the preceding claims, wherein the guide further comprises a plasma termination device so as to attenuate the supply of electrically charged species to the substrate.

5 10. Apparatus according to claim 9, wherein the plasma termination device is an electrically conducting mesh.

11. Apparatus according to claim 9, wherein the plasma termination device is a magnet.

10 12. Apparatus according to any of the preceding claims, wherein the material comprising at least the surface of the guide for contacting the gas flow, is arranged to prevent the quenching of active species within the gas flow.

13. Apparatus according to any of the preceding claims, further comprising a heating system arranged to heat the guide to a predetermined temperature when in use.

15 14. Apparatus according to any of the preceding claims, wherein the guide is detachable.

15. Apparatus according to any of claims 1 to 13, wherein the guide is formed from the chamber walls.

20 16. Apparatus according to any of the preceding claims, wherein the plasma generator comprises at least one of an induction coupled plasma generator, a microwave plasma generator or an electrode plasma generator.

25 17. Apparatus according to any of the preceding claims, further comprising support means for supporting the substrate.

18. Apparatus according to claim 17, wherein the support means is located within the chamber.

30 19. Apparatus according to claim 17 or claim 18, wherein the support means is moveable so as to provide a variable distance between the plasma and the substrate.

20. Apparatus according to any of claims 17 to 19, wherein the guide is mounted to the support means.

35 21. Apparatus according to any of claims 17 to 20, further comprising an electrical supply system adapted to supply electrical power to the support means.

22. A method for plasma treating a substrate comprising:-

causing one or more gases to flow within a chamber;  
forming a plasma from the gas(es) within the chamber  
using a plasma generator, thereby generating at least one  
species; and

5 directing the gas flow containing the species towards  
the substrate;

wherein the width of the plasma in use is greater than  
that of the substrate, the difference between the widths  
defining an outer region of plasma, and wherein the species  
10 are directed from at least the outer region, towards the  
substrate.

23. A method according to claim 22, wherein the plasma is  
an induction coupled plasma.

24. A method according to claim 23, wherein an electrical  
15 power is provided to the substrate so as to control the  
interaction of the species with the substrate.

25. A method according to claim 24, wherein the electrical  
potential is an RF potential.

26. A method according to any of claims 22 to 25, wherein  
20 the gas pressure within the chamber is in the range 1 to 15  
Pa.

27. A method according to any of claims 22 to 26, wherein  
the gas(es) comprise one or more of  $\text{SF}_6$ , chlorine,  
fluorocarbon compounds, nitrogen, oxygen or silane.

28. A method according to any of claims 22 to 27, wherein  
25 the power input of the plasma generator is about 5 kW.

29. A method according to any of claims 22 to 28, wherein  
the gas flow rate is about 500 standard cubic centimetres  
per minute.

30. A method according to any of claims 22 to 29, wherein  
30 the plasma treatment comprises an etching treatment.

31. A method according to any of claims 22 to 30, wherein  
the plasma treatment comprises a deposition treatment.

32. A method according to any of claims 22 to 31, wherein  
35 at least the species generated substantially at or adjacent  
the periphery of the plasma are guided onto the substrate.

33. A method according to any of claims 22 to 32, further comprising directing the gas(es) introduced into the chamber towards the most active region(s) of the plasma.

5 34. A method according to any of claims 22 to 33, further comprising causing a nett flow of the species across the substrate.

35. A method according to any of claims 22 to 34, using apparatus according to any of claims 1 to 21.

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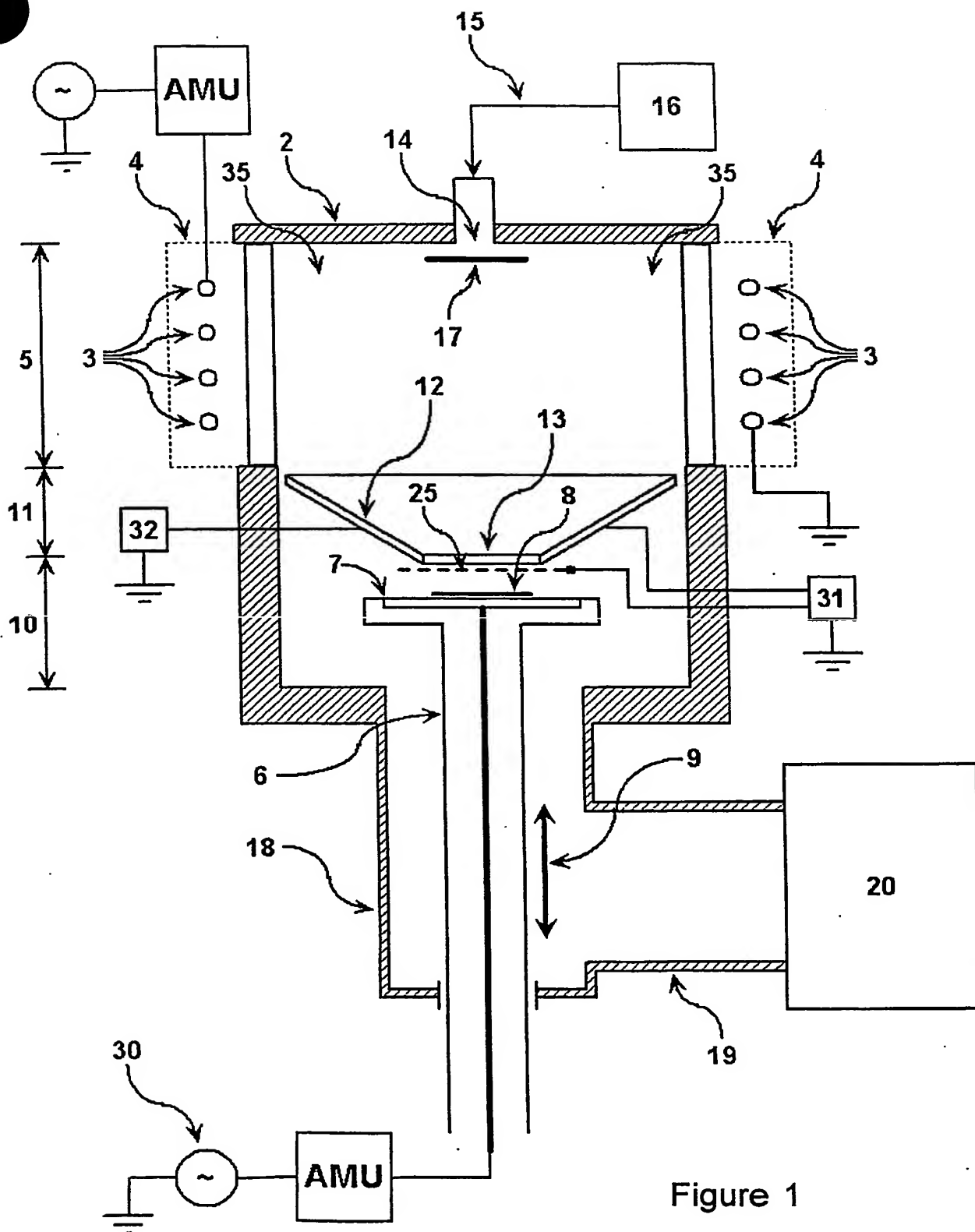


Figure 1

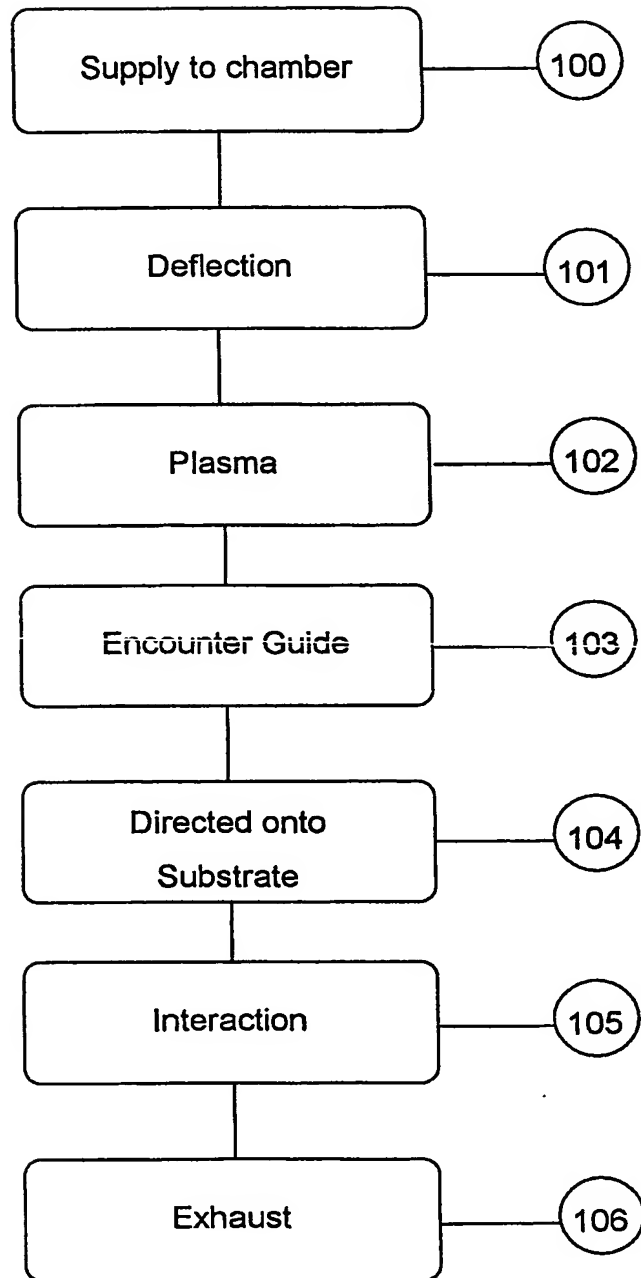


Figure 2

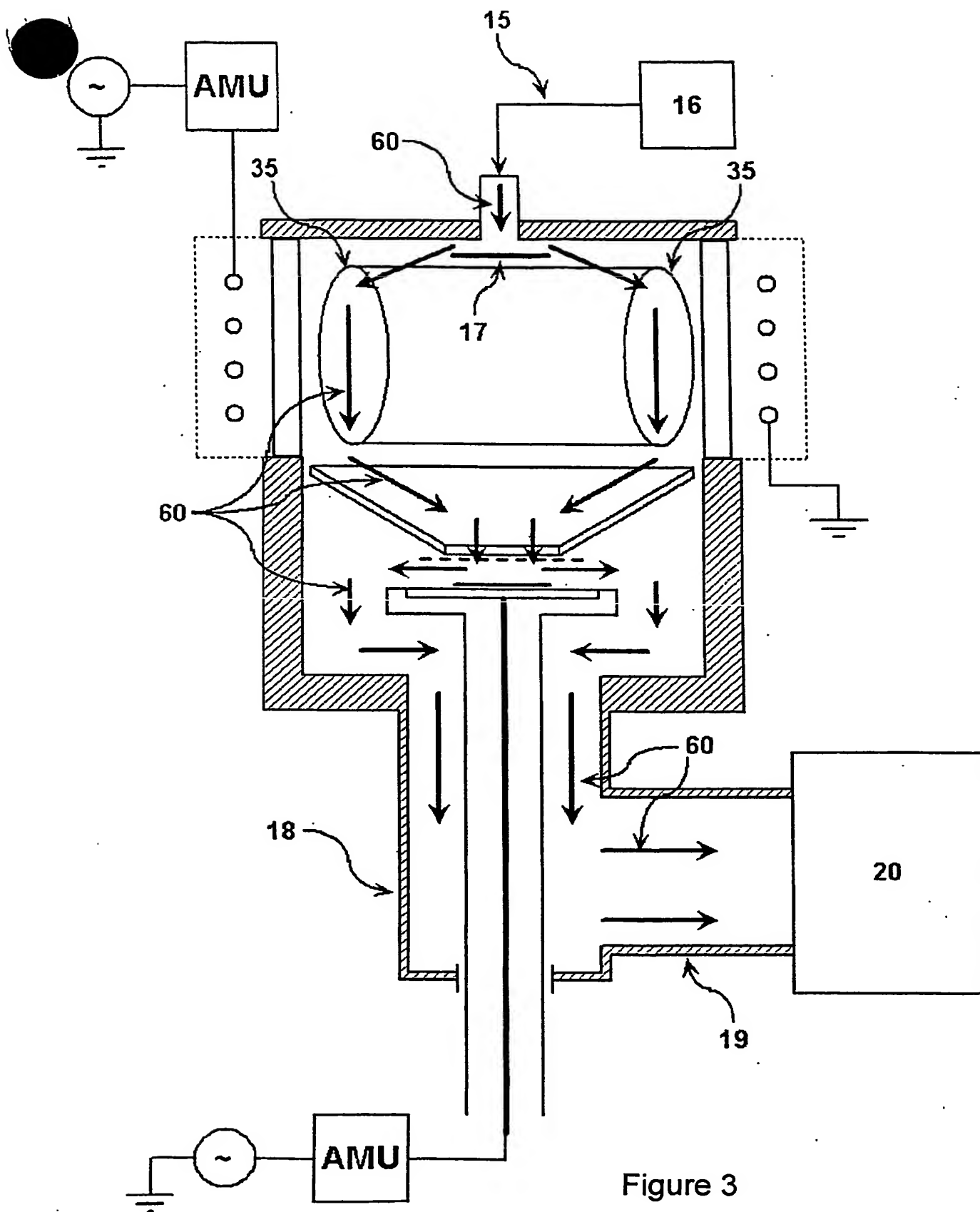
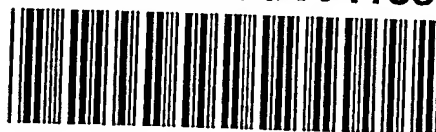


Figure 3

PCT/GB2004/004158



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- ☐ **GRAY SCALE DOCUMENTS**
- ☒ **LINES OR MARKS ON ORIGINAL DOCUMENT**
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